Effects of Continuously and Discontinuously Moving Stimuli on the Luminance Threshold of a Stationary Stimulus

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The effects of a moving line of light on the luminance threshold of a stationary target in its path have been compared for continuous and interrupted movement with three luminances of the moving line (2.0 to 0.023 ft-L), four speeds (17° to 170°/sec), and four widths of interruption of movement about the target position (0.13° to 3.43°). For both the continuous and interrupted movement the target threshold generally varied (a) with the luminance of the line divided by its speed, and (b) with the temporal interval between the presentation of the target and the arrival of the moving line at the target position. At short temporal intervals the rise in threshold with increasing luminance of the line was much greater than at long intervals. Although there were no substantial changes in the slopes of the functions, the point of maximum threshold rise was a function of speed. Both inhibitory and facilitative effects were magnified with very small interruptions of movement but decreased with larger interruptions.

IN a previous study, Luria and Kolers[1] investigated the masking effects of a moving line on a stationary test stimulus in its path. There had been many investigations of the masking effects of stationary stimuli[2-8] but apparently no investigation of the effects of a moving stimulus. The recent discoveries of specific-movement detectors in lower animals[9,10] made comparison studies desirable. Luria and Kolers concluded that changes in the threshold of the test stimulus are a function of the luminance of the line, but that the rate of change is a function of the temporal relations between target and line; there appeared to be no substantial differences as a function of the direction of movement. In that experiment, the test stimulus was generally seen as superimposed on an extended field of light produced by the moving line; to the observer it appeared, then, that contrast thresholds were being measured. The purpose of the present study was to determine, by blocking the movement of the line for varying distances around the test stimulus, (a) if there are changes in the functions when this phenomenon is precluded, and (b) the range over which the inhibitory effects operate.

APPARATUS

A pendulum 4.5 ft long controlled the presentation of both the moving line and the test stimulus flashed in its path. The bob of the pendulum was 18 in. wide and 12 in high with two vertical slits cut in it, one above the other (Fig. 1). The upper of these MS could be moved horizontally, while the lower slit FS was fixed. A second fixed slit SS was positioned behind the movable slit. Thus, when the pendulum moved through one swing, a single vertical bar of light (through FS) moved across the viewing screen, while another stationary bar of light, the test stimulus, appeared for the brief portion of the swing during which MS and SS were aligned. By varying the position of MS with respect to FS, the test stimulus was made to appear in its fixed position when the moving line was at one of several points in its traverse. Baffles B permitted only the center 1-in. segment of the arc of the pendulum to be used. Another set of baffles was inserted in this plane to block the projection of the line for some part of its traverse. The speed of the line was determined by the height from which the pendulum was released.

The optical system is diagramed in Fig. 1. The light from a 750-W projection lamp LS, maintained at 110 V ac by a General Radio automatic voltage regulator, was collimated into two beams. One beam was focused at the plane of the pendulum bob at FS and again on the viewing screen SC. The second beam was directed by
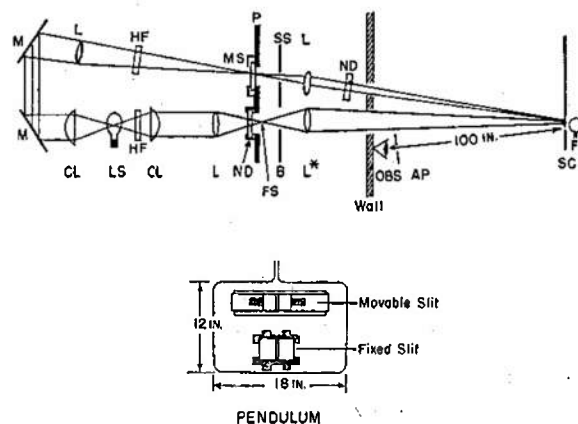

FIG. 1. A side view of the optical arrangement in the upper figure. The heavy black line P is the pendulum bob with its fixed FS and movable MS slits (also shown in front view in the lower figure) and the stationary slit SS behind it. Also shown are the light source LS, collimating lenses CL, heat filters HF, mirrors M, lenses L, neutral density filters ND, artificial pupil AP, viewing screen SC, and fixation light FL. Baffles B set the limits of the movement of the line projected on the screen.

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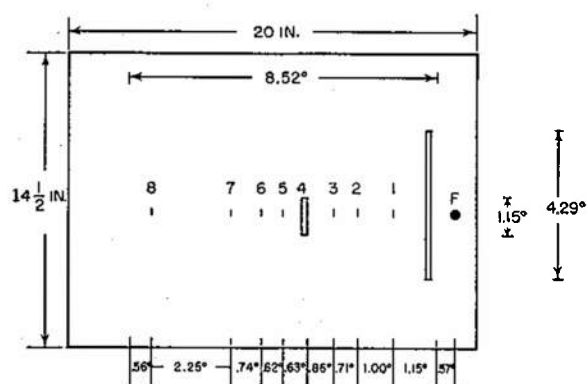[10] D. Hubel and T. Wiesel, J. Physiol. (London) 160, 106 (1962).

FIG. 2. Diagram of the viewing screen showing the location of the test stimulus (point 4) 4.29° to the left of the fixation light F and the eight positions of the moving line when the threshold of the target was measured. The separations between the points are shown in degrees visual angle. The line moved through 8.52° toward the fixation light.

mirrors and then brought to a focus first at the plane of the bob at MS and again on the screen. The test stimulus appeared in the middle portion of the moving line but was much shorter than it. The test stimulus was 1.15° high and 0.058° wide; the movable line was 4.29° high and 0.036° wide.

Four widths of baffle were used to block the projection of the line symmetrically about the position of the target for 0.13°, 0.72°, 2.00°, and 3.43° visual angle.

The maximum luminance of the moving line, as measured with a Spectra brightness spot meter, was 2 ft-L; the maximum luminance of the test stimulus was 1 ft-L; the luminance of the screen on which the lines appeared was 2.2×10^{-6} ft-L, just above threshold. Filters ND placed in the optical path of both the line and the test stimulus controlled their luminance.

The viewing screen, diagramed in Fig. 2, was 20 in. wide, 14.5 in. high and 100 in. from the observer's eye. The moving line traversed 8.52° of this screen toward the fixation point F, a small red light. The numbers 1–8 show the position of the line when the test stimulus was presented. The test stimulus always appeared at point 4, 4.29° to the left of the fixation point.

Observations were made from a curtained booth in a dark room. The observer's head was held by a forehead and chin rest, and he looked through an artificial pupil. Measurements were made of observers' pupils before the experiment with an infrared pupilometer while they viewed both the moving and stationary stimuli at their greatest luminances. The pupils were never seen to constrict to less than about 5.75 mm, and so a 5-mm artificial pupil was used.

It was desirable to make the exposure time of the test stimulus as brief as possible to minimize the extent of the sweep of the line while the test stimulus was exposed. But the large light losses through the double slits (MS and SS) set a practical limit to this reduction; the width of the slits was so set that the duration of the test stimulus was one-tenth of the total traverse time of the pendulum across the screen.

CALIBRATION

Two calibrations were performed with an oscilloscope and an RCA 929 phototube positioned either beyond the lens L* at a point where the traverse of the moving beam of light was about 1 in. or beyond the lens in back of SS.

First the swing of the pendulum was calibrated. Points were established from which to release the pendulum so that it required 50, 100, 200, or 500 msec for the projected line to cross the screen (equivalent to 170°, 85°, 43°, and 17°/sec). The duration of the test-stimulus, accordingly, was 5, 10, 20, or 50 msec. Variations in these values were less than 5%.

Second, the speed of the moving line during the central 2 in. of its traverse was compared with its speed at both extreme 2-in. segments. Although the speed of a pendulum is greatest at the bottom of its swing, the traverse time of the projected line was found to be about 5% greater at the center than at the ends, presumably due to the flat screen: 2 in. represents a smaller visual angle at the edges of the field than at the center.

The duration of the test stimulus was set by adjusting its baffle so that the stimulus remained on while the projected line moved through one-tenth of its traverse across the screen.

The variations in the target exposure times result, of course, in differences in luminance thresholds. These are shown in Fig. 3, averaged for the three observers. The differences amount to less than 0.07 ft-L, much less than the range found in the study.

OBSERVERS

Three experienced observers were used, two emmetropes and a myope who wore his spectacle correction while observing.

PROCEDURE

Two sets of data were obtained in each session. One set was taken with uninterrupted movement, the other
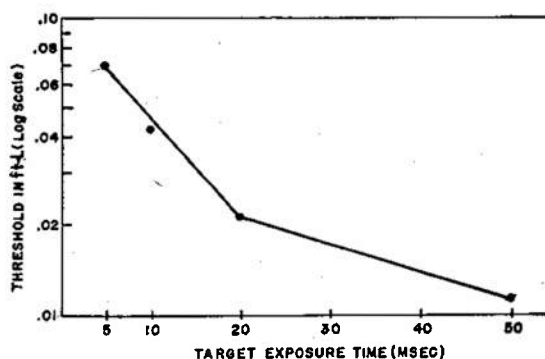

FIG. 3. The luminance threshold of the target as a function of its exposure time.
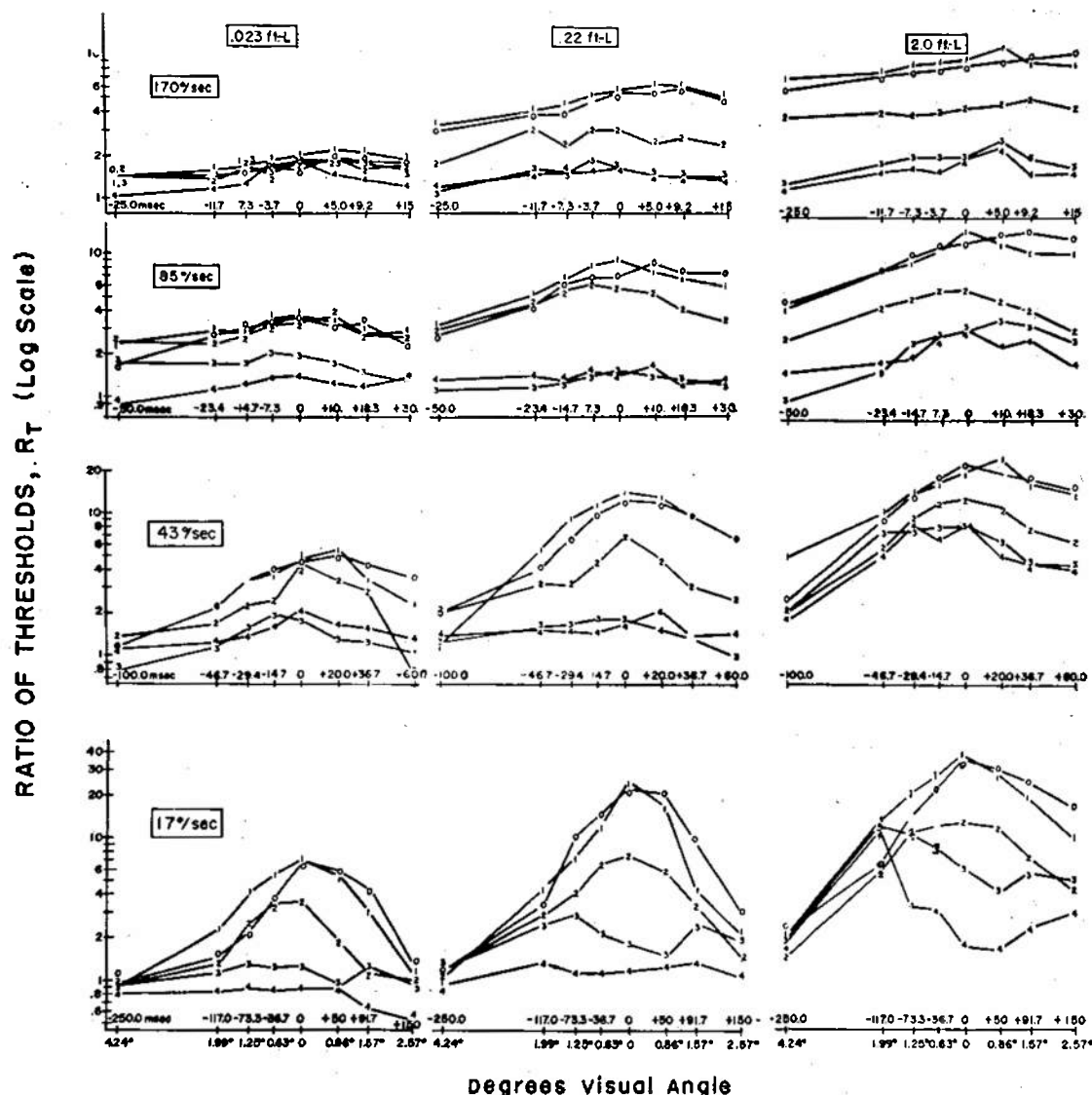
FIG. 4. The threshold ratios R_T as a function of the separation between the target and the moving line. Each horizontal set of graphs is for a different speed; each vertical set of graphs is for a different luminance. Each curve within a set is for a different width of interruption of movement: (0) no interruption; (1) 0.13°; (2) 0.72°; (3) 2.00°; (4) 3.43°. The spatial separation of the target and line is shown in degrees visual angle, and the equivalent temporal separation for the different speeds is shown on each graph. Negative times indicate that the target was presented before the line reached the position of the target.

with one of the four widths of baffle which blocked out the movement around the target position. Thus, the effect of a given baffle could be compared to the effects of continuous movement during one session. Each session measured the effects of one speed and luminance of the line, presented in random orders to the three observers. Since there were four baffles and for each baffle the corresponding condition of speed and luminance was repeated for the continuous movement, the curves showing the effects of continuous movement are the average of four sessions for each observer, while the results of interrupted movement are based on only one session. Each set of data was composed of nine threshold

measurements, one for the target alone and one for each of the eight separations between the line and target, taken in random order.

The target thresholds were measured with the method of limits, varying the target luminance in 0.1 log unit steps. The measurements were always begun with the descending series; if begun with the ascending series, the observers had difficulty in localizing the target. The average of the ascending and descending series comprised one threshold measurement. Observations were made monocularly with the right eye.

A session was begun with a 15 min period of dark adaptation and a few practice trials. The observer was

alerted about 1 sec before each presentation. He was allowed to request a repetition of a presentation if he had blinked or been unready. The presentations were made once every 8 sec. A session, including dark adaptation, lasted less than an hour.

RESULTS

The data are presented as ratios of the threshold of the target in the presence of a moving line to the threshold of the target by itself. In Fig. 4, the logs of the threshold ratios (R_T) are plotted as functions of the separation between the moving line and target. Data are given for three parameters; luminance, speed, and the width of interruption of the movement. The 12 sets of curves are grouped horizontally by speed and vertically by luminance. Each set of 5 curves shows the results at a given speed and luminance. In each set, a given curve shows the effects with either no interruption of movement (0) or with one of the four widths of interruption (1–4). The points showing the effects of no interruption of movement are the mean of four measurements for each of the three observers, while the points showing the effects of a given width of interruption are the mean of one measurement for each observer.

Effect of Separation between Moving Line and Target

R_T increases as the separation between moving line and target decreases and generally reaches a maximum when the target and line are more or less in synchrony. The rate of increase is greater when the line is approaching the target than after it has passed over the target and is moving away.

The introduction of the baffles produces several effects. In general, when the movement is blocked for small distances, curves are obtained similar to those for continuous movement, while when the movement is blocked for larger distances much less inhibition is produced. More specifically, when the movement of the line is blocked for only a very short distance (0.13°) around the test stimulus, the maximum R_T is invariably higher than in the presence of continuous movement; as the line approaches the target, R_T is often higher with the baffle, but as the line moves away from the target, R_T is almost invariably lower. With the smallest baffle, then, a curve is produced which has a higher peak and tends to be more symmetrical about the peak than is the case with continuous movement. As the width of interruption is increased, maximum R_T decreases and increasingly shallower curves are produced, but most of the decrease generally appears to have occurred with an interruption of movement about the target of 2.0°. At the slowest speed, however, the two largest baffles produce curves which do not rise to a maximum near the target position, but rather approach no effect.

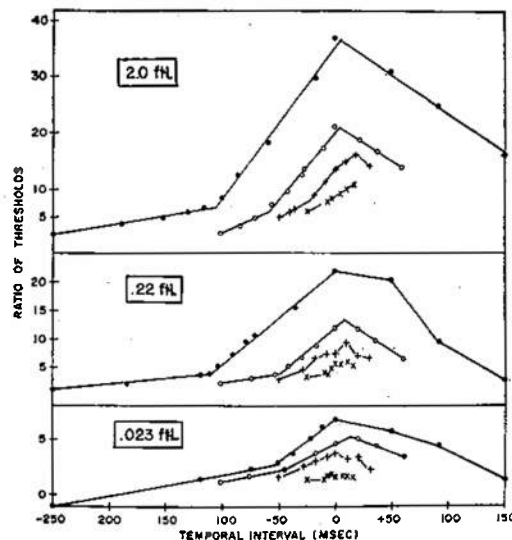In certain cases, lower thresholds have been obtained

FIG. 5. The threshold ratios R_T as a function of the temporal separation between target and moving line for continuous movement of the line.

in the presence of the line than when the line was absent. With continuous movement this has occurred for all observers at the largest separation on the curve for the slowest, dimmest line, and with the largest baffle, every threshold comprising this curve was lower in the presence of the moving line.

A spatial separation is also a temporal separation for a given speed of line. The temporal values of arbitrary points along the "0" curves of Fig. 4 have been replotted in Fig. 5 with the four speeds grouped according to luminance. A positive temporal interval indicates that the line has passed through the target position before the target was presented; a negative temporal interval indicates that the target was presented before the line passed through its position. In Fig. 4, R_T was plotted on a log scale to emphasize the "facilitation" effects. In Fig. 5, however, R_T has been plotted on a linear scale; this plot makes much clearer what is not easily seen in Fig. 4: the curves appear to be straight-line functions with two arms as the line approaches the target. The increase in R_T is relatively slow until a certain separation is reached after which there is an increase in slope. This "break" in the curves is much less apparent at the faster speeds than at the slower speeds, but at a given speed, it appears to be roughly constant with luminance. It occurs at about 100 msec for the slowest speed (at its two highest luminances), and about 50 msec for the next speed; the break is more difficult to discern at the faster speeds, but would seem to occur at about 10 msec for the fastest speed and around 20–30 msec for the next-fastest speed. When the line recedes from the target, however, there is no such break in the linear functions.

When the curves for interrupted movement are so replotted (not shown), the two narrowest baffles produce functions with the break at the slowest speed (17°/sec);
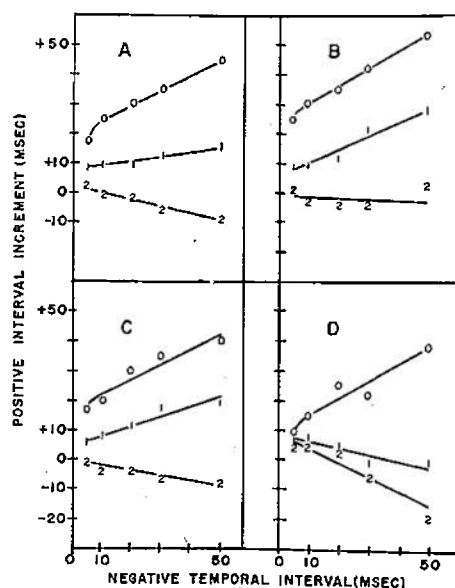
FIG. 6. The negative and positive intervals at which equal R_T occurs. The negative interval has been subtracted from the positive interval to give the increment which must be added to the negative interval to give the time at which the equal R_T is found. (A) the average of all speeds and luminances, (B) highest luminance averaged across speeds, (C) intermediate luminance averaged across speeds, and (D) lowest luminance averaged across speeds. The "0" function shows results for continuous movement, "1" for 0.13° baffle, "2" for 0.72° baffle.

at 43°/sec the change in slope is much less, and the break is not seen at the two fastest speeds (85° and 170°/sec). The functions for the two largest baffles never show the break.

The positive and negative temporal intervals at which equal R_T's were obtained with either no baffle or with the two smallest baffles are compared in Fig. 6. These values were taken from Fig. 4 with the assumption that the functions were straight lines and, when necessary, extrapolating them if possible. In Fig. 6 the ordinate shows the positive intervals minus the corresponding negative intervals; this difference is the "positive interval increment." If the functions were perfectly symmetrical, the graph would show a horizontal line at an ordinate value of zero; insofar as the positive intervals are larger or smaller than the corresponding negative intervals, the line is above or below zero. Figure 6 (A) shows these data averaged for speed and luminance; they are broken down by luminance in (B) bright, (C) intermediate, and (D) dim luminance, averaged over all speeds.

The changes in the positive intervals are a function of both the width of interruption and luminance. With continuous movement, the positive intervals averaged for both speed and luminance (A) are greatly minimized by the smallest baffle, while the next-larger baffle results in smaller positive then negative intervals. When these results are broken down by luminance, we see that with continuous movement there is no change in the slopes of the functions, although they are displaced downward by decreasing luminance. Thus, for a given luminance

there is some constant increment (which is larger with increasing luminance) in the positive intervals. With the baffles, lowered luminance results in both a general downward displacement and changes in the slopes of the functions; the latter indicate an increasing decrement with increasing size of negative interval.

Effect of Luminance

For all conditions of position and speed in the presence of continuous movement, an increase in the luminance of the moving line produced both an increase in the slope of the function (Fig. 5) and an increase in R_T. The latter is shown in Fig. 7 in which the average maximum R_T is plotted as a function of the log luminance for the four speeds. Each speed produced a separate curve which appears to be slightly negatively accelerating as the luminance is increased. For a given luminance, R_T increases as the speed decreases; that is, the masking effect of the moving line is greater when it is moving more slowly. And since a line of a given luminance appeared dimmer as its speed increased, it indicated that the luminance of the line divided by its speed is a better expression of the "effective" luminance of the moving line. When maximum R_T is plotted against luminance/speed (Fig. 8), the points appear to describe a linear function.

The results with the baffles are not as clear, doubtless owing to the smaller number of observations per point. Because of the change in the shape of the curves with the large baffles and slow speed, it is difficult to decide whether to plot the maximum R_T under a given set of conditions or R_T at a constant separation between line and target. Since all the baffles block out the movement of the line symmetrically about the target, the curves for the interrupted movement have been plotted showing R_T at synchrony.
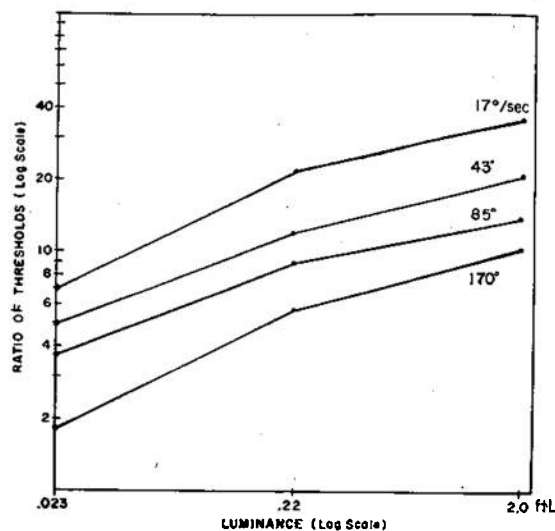

FIG. 7. Maximum threshold ratios as a function of the luminance of the moving line for continuous movement.
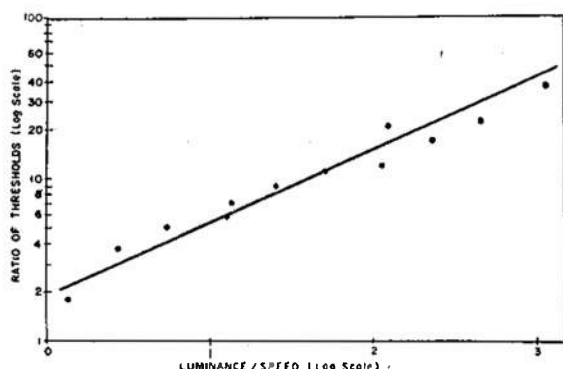
FIG. 8. Maximum threshold ratios as a function of the luminance of the line divided by its speed for continuous movement.

Figure 9 shows that for a given position, speed, and baffle, an increase in the luminance of the line generally produced an increase in R_T. For the smallest one or two baffles, the functions are negatively accelerated as the luminance increased, while for the largest two baffles they are positively accelerated. For a given luminance and baffle, R_T again decreases with increasing speed.

An over-all summary of the effects of separation and luminance with the various baffles is best seen with a three-dimensional representation. This has been drawn in Fig. 10. It shows R_T at synchrony as a function of both (a) temporal separation between the presentation of the target and the disappearance of the moving line and (b) the "effective" luminance (luminance/speed). The straight-line function in Fig. 8 is not seen here because R_T has been plotted on a linear rather than a log scale; the later grossly exaggerates the small differences at the short temporal intervals and low luminances. Although the surface is not completely smooth, it is quite clear that R_T increases both as a function of decreasing temporal separation and increasing effective luminance. Moreover, there is an interaction effect between luminance and temporal separation such that

the effect of the former increases markedly with decreasing temporal interval.

Effect of Speed

We have seen that speed affects the maximum amplitude of the curves only insofar as it changes the effective luminance of the moving line. Changes in speed also have little effect on the shapes of the curves. Figure 5 shows that the slopes of all the curves at a given luminance are quite similar when plotted on a temporal abscissa.

Speed does have an effect, however, on the position of the peak of the curves (Fig. 4). As noted above, R_T generally increases as the separation between line and target decreases. For the slowest speed, R_T is a maximum at synchrony at all luminances, but as the speed in-
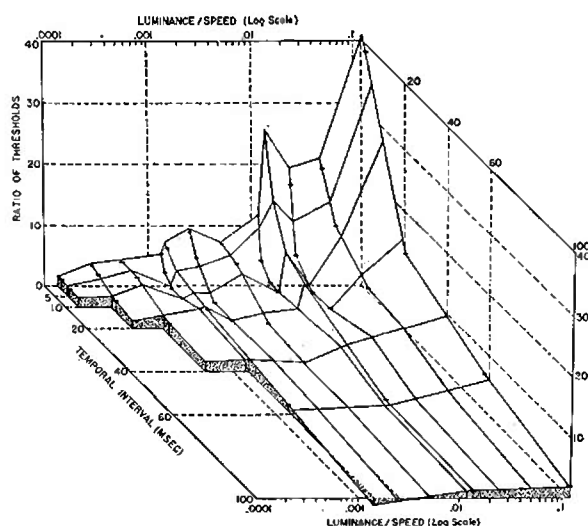
FIG. 10. A three-dimensional representation of the results for interrupted movement showing the threshold ratios as a function both of (a) the temporal interval between the interruption of movement and the presentation of the target and (b) the luminance of the moving line divided by its speed.

creases, the maximum tends to occur at increasing separations after the line has passed the target position. Indeed, the curve for the brightest, fastest line shows no sign of decreasing. Figure 11 shows that the spatial separation between the target position and the line at the point of maximum R_T, averaged by individual session for all observers, increases as a function of speed. When, however, these spatial shifts are replotted as temporal intervals, the curve becomes rather flat.

Figure 12 shows that the spatial separation (or temporal interval) at the higher speeds increases with increasing luminance.

DISCUSSION

The experiment has shown that a moving stimulus modifies the threshold of a stationary target in its path. As with stationary masking stimuli, (1) the
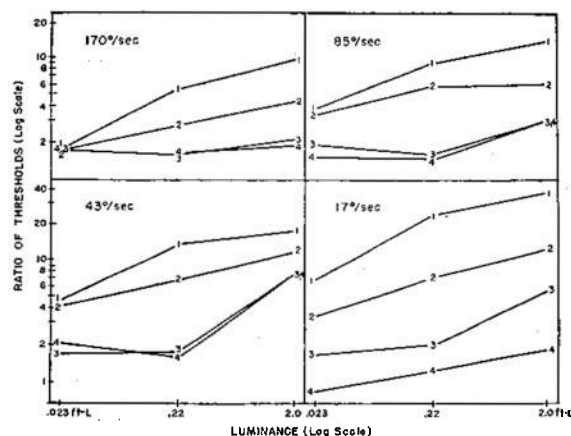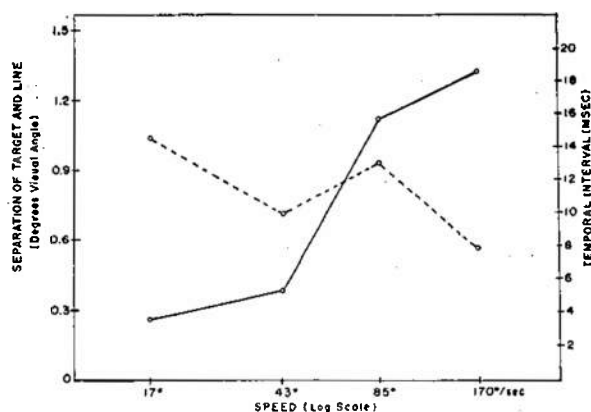

FIG. 9. Threshold ratios at synchrony as a function of the luminance of the moving line for various widths of interruption of movement: (1) 0.13°, (2) 0.72°, (3) 2.00°, (4) 3.43°.

FIG. 11. Separation of the line and target at which maximum threshold ratio is obtained as a function of the speed of the line (spatial separation ●——● ; temporal separation ○-‑‑‑○).

threshold of the target decreases with increasing separation. It may, under certain conditions, be even lower than when it is presented by itself; (2) the target threshold increases with increasing luminance of the moving stimulus, but with a moving stimulus it is necessary to take into account the speed of the latter as well as its measured luminance; (3) the threshold of the target is affected when it is presented either before the moving line has passed over the target position or afterwards. For a given set of conditions, the threshold is higher in the latter case.

The data from the interrupted movement indicate that the rise in threshold occurs whether the test stimulus is seen against a light or dark background and is a neural effect. That the effect is sometimes facilitative rather than inhibitory shows that it is not due merely to stray light. Further, at a given separation with continuous movement, the target threshold is higher when the line has first passed over the target (positive temporal intervals). One reason must be that, in addition to the inhibitory effect occurring across the spatial separation, there is the stimulation by the line on the target position on the retina. When even a small baffle is inserted to prevent stimulation of the target position by the line, the thresholds measured at equal intervals on either side of the target are more nearly equal, and the functions become more symmetrical. But it is clear that the difference in time needed to equalize the two thresholds is not merely the time required for the receptors to recover from the additional stimulation. If this were the only cause, the "1" and "2" curves in Fig. 6 would presumably be horizontal lines at zero, showing R_T to be the same at equal positive and negative intervals. This is not the case, so while it may be one pertinent factor, there must also be others.

Figure 6 shows that for continuous movement, the functions are displaced upward with increasing luminance, but the slope remains constant; that is, R_T at positive intervals is greater than at negative intervals by some constant factor, but this factor increases with

increasing luminance. In contrast, the functions for interrupted movement show a decreasing slope with decreasing luminance. It is possible that the slope of the "1" curves is not horizontal partly because this baffle is very narrow and there is irradiation into the target region. The amount of irradiation would decrease with decreasing luminance, causing the decrease in the slope of the "1" curves. Increasing the size of the baffle would also decrease the amount of irradiation; Fig. 6 shows that at the highest luminance, the function for the "2" baffle is indeed horizontal and its slope decreases with decreasing luminance.

At the lowest luminance for the "1" baffle and at the two lower luminances for the "2" baffle, the slope of the functions becomes negative; that is, R_T is less at positive than negative intervals. This suggests that under these conditions, not only is irradiation no longer a factor, but the phenomenon of "disinhibition" is occurring. Hartline and Ratliff[11] originally discovered this effect in *limulus*, but it has since been noted in humans.[12,13] The conditions for disinhibition are obviously present with the baffles. There is stimulation of one part of the retina by the line, but no stimulation for a distance between the line and target; thus the presence of the line may inhibit the receptors in the intervening gap which in turn "disinhibits" the receptors in the target area and results in a lower threshold than expected.

Why, however, does disinhibition appear for positive rather than negative intervals? This must be the result of the direction of movement and the generally higher
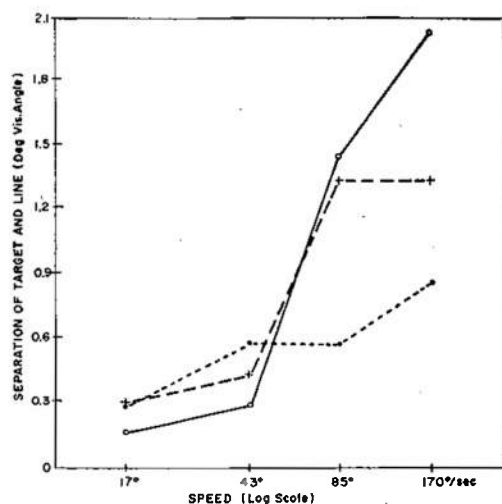

FIG. 12. The average separation of line and target at which the maximum threshold ratio occurs as a function of the speed of the line (○——○ 2.0 ft-L; +‑‑‑‑+ 0.22 ft-L; ●·····● 0.023 ft-L).

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[11] H. Hartline and F. Ratliff, J. Gen. Physiol. 40, 357 (1957); 42, 1241 (1959).

[12] W. R. MacKavey, S. H. Bartley, and C. Casella, J. Opt. Soc. Am. 52, 85 (1962).

[13] M. Alpern and H. David, J. Gen. Physiol. 43, 109 (1959).

luminance of the line than the target. The target threshold is measured at a nominal separation between line and target. When the line is approaching the target, further movement after the target has been presented brings it nearer the target. This added movement results in receptor responses which occur nominally after the response to the target. But since the line luminance is generally much higher than that of the target, the latencies of the responses to the former are no doubt shorter. This could result in the line affecting the target threshold after the target has been presented, and the effect could be exaggerated both because the separation of target and line is reduced and because there may be a cumulative effect over the total traverse of the line. For positive intervals, on the other hand, further movement of the line after presentation of the target carries it away from the target area, and there is neither the reduction of the separation nor any cumulative effects from the traverse of the line. In this way thresholds for positive intervals could be smaller than those for negative intervals.

A much more clear-cut example of "disinhibition," apparently, is the lower target threshold under certain conditions in the presence of the line than when the target is presented by itself. This may be related to the question of whether the course of dark adaptation can be hastened by the presence of dim lights[14] and to the finding that the more stimuli presented in the field of vision, the more likely each is to be seen.[15]

When the movement of the line is blocked for a very short distance around the target position, the thresholds at synchrony were greater than those thresholds obtained with continuous movement. Since it has previously been shown[1] that target thresholds, measured at synchrony, increase as the point of onset of the moving line approaches the target but do not vary as a function of the point of termination, the rise in threshold is, therefore, probably due to a burst of "on-responses" occurring with the onset of movement or, in the present experiment, with the reappearance of the line.

The data with the interrupted movement have also made clearer that the effects are a function of both the effective luminance of the moving line and the temporal separation between line and target. What is not completely clear is whether R_T is constant for the combination of a given temporal interval and effective luminance. Figure 9 suggests that this is the case, since the surface of the solid is reasonably smooth. The data,

however, provide only two pairs of curves with equivalent luminances, the fastest and slowest speeds at two sets of luminances; their comparison is limited since the maximum temporal interval for the fastest speed is only 25 msec. Nevertheless, comparing the curve for 170°/sec at 0.22 ft-L with that for 17°/sec at 0.023 ft-L in Fig. 5, we note that R_T at a temporal interval of −25 msec is about 3 for the former and about 5 for the latter; at an interval of +15 msec it is about 5 for the former and 6.5 for the latter. These values are quite comparable, but the values for these two speeds at the next highest luminances are not. Whether this is due to such factors as the extended period of time over which the data were collected, for example, remains to be determined.

As the line approaches the target, the rise in threshold is slow at larger separations and then suddenly increases (Fig. 5). The "break" in the curve is roughly constant for a given speed. Since it occurs at a separation of about 100 msec for the 17°/sec speed and around 10 msec for the 170°/sec speed, apparently, then, the sudden rise begins when the moving line is around 1.5° from the target. A possible explanation is that around this point the line enters the same receptor field which the target stimulates. This break is never clearly seen with the two larger baffles which block the movement of the line within 1° of the target.

The curves with the two largest baffles and the two slowest speeds show a dip rather than a rise in R_T at synchrony. These curves also, however, resemble curves reported[16] for spatially separated stationary stimuli whose luminance, spatial separation between target and masking stimulus, and temporal values were comparable.

The shift in the position of the peaks of the curves with changes in the speed of the line must be an indication of the latency of the masking effect. Although the average spatial separation between line and target at which the maximum threshold occurs increases as the speed increases, these spatial differences reflect a constant temporal interval. Luminance is also a factor. Since maximum R_T occurs at greater intervals with increasing luminance (Fig. 11), it apparently does not occur at temporal synchrony but rather when the target precedes the line by a given amount (as Alpern found, for example, for metacontrast[5]). With increasing luminance, since the latency of the response to the line should decrease, the temporal intervals between line and target should increase, resulting in a greater spatial separation between them.

[14] Y. Legrand, *Light, Colour and Vision* (John Wiley & Sons, Inc., New York, 1957), p. 240.
[15] G. Fooks, E. Sweeney, and F. L. Dimmick, U. S. Naval Medical Research Laboratory Report No. 285 (June 1957).

[16] P. A. Kolers, Vision Res. 3, 191 (1963).